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Performance Monitoring in the Next Generation of Optical Networks

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Abstract: This paper discusses the requirements for optical performance monitoring in all-optical networks. Investigations show that current monitoring technologies are not sufficient for the optically switched networks and that several performance monitoring operations need to be moved down to the physical layer. Furthermore, three experimental examples of optical performance monitoring are presented; dispersion monitoring, OSNR monitoring and all-optical parity checking.

Keywords: Optical communication systems, optical networks, performance monitoring.

1. Introduction

Optical communication networks have over the past years developed into high-capacity and high transmission distance systems. With the introduction of optical switching the optical networks are furthermore becoming increasingly flexible and transparent. Several signals of various origins can theoretically be transmitted in the same optical fibre and switched as desired while keeping the signal in the optical domain at all times. The optical switching technology opens up for a wide spectrum of possibilities in terms of optical transport flexibility. This flexibility however, comes at the price of a much more complicated and problematic approach to performance monitoring in all optical networks compared to the earlier legacy approach [1].

Performance monitoring is a vital part of digital communication systems. It is necessary to detect and prevent errors in order to maintain carrier uptime and quality of service (QoS) agreements. Often the required availability is specified as 99.999%, which means that only 5 minutes of down-time within one year is acceptable. In order to verify and assure that the guaranteed limits are kept, accurate performance monitoring as well as network protection is necessary.

This paper will address the changes required in performance monitoring technologies in order to comply with the next generation of optically switched networks. The paper will also address the issue of what parameters should be monitored in the optical signal as well as the technologies used for monitoring signal quality in an all optical network.

2. Layered Performance Monitoring

First, it should be noted that the general term *optical performance monitoring* in this context refers to performance monitoring of optical signals only. Optical performance monitoring is further divided into categories of *optical signal parameter monitoring* such as wavelength, PMD, dispersion and OSNR monitoring, and *optical signal quality monitoring*, which covers bit-error monitoring and

Q-value monitoring primarily, i.e. methods for direct signal quality estimation.

Performance monitoring in communication networks can and should be done in several of the network layers. Going from the physical layer to the transmission layer and further up, each layer carries a part of the responsibility to assure the data integrity. Monitoring in the physical layer, which can be the optical channel in a fibre, includes monitoring of wavelength, wavelength drift, channel power and total WDM power to mention the most significant parameters considering today's optical communications networks. These parameters are of physical nature, and will give no indication of the signal quality except from loss of signal (LOS) indications. Performance monitoring in the physical layer is in fact normally dominated by optical signal parameter monitoring.

Today's performance monitoring in the transport layer is typically managed by SDH or SONET and is currently the lowest layer where signal quality monitoring is performed, and in this case, via a bit-error evaluation (BIP-8) [2]. The higher layers such as the switching and the routing layers can also include capabilities for performance monitoring (Figure 1). For example asynchronous transfer mode (ATM), which is able to make classes of service (CoS) and QoS differentiation based on requirements to the packet loss ratio and delay performance. This paper however, focuses on optical performance monitoring in the physical layer, including both optical signal parameter monitoring and optical signal quality monitoring.

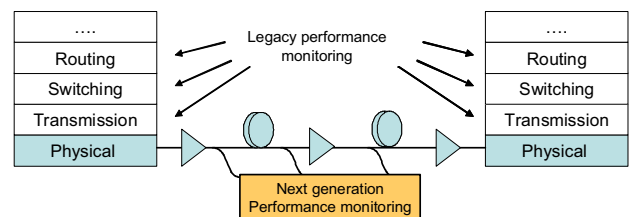


Figure 1: Performance monitoring is done in several layers of the network. More monitoring functionalities should be done in the physical layer in next generation optical networks.

3. What should be monitored?

A fully flexible all-optical network would imply almost infinitely many combinations of signals types in the optical fibre. Therefore, it is a very comprehensive task to perform optical signal quality monitoring on every thinkable signal that might be switched into a particular transmission path at any given time. However, with certain basic assumptions, the problem can be somewhat simplified. Some examples are given below:

- Fully dispersion compensated spans. This simplifies dispersion monitoring considerably as the monitoring can be done on the span rather than on individual channels.

- Consider the case where a monitor signal is associated with each channel. If each channel carries a relevant monitor signal of some kind, the signals can be monitored individually within the network.
- There exist some limitations as to which signals are allowed in the network. For example bit-rate and modulation format restrictions. This would effectively reduce the performance monitoring complexity.

The last point obviously removes partly the idea about the transparent all-optical network, but a performance monitoring technique capable of monitoring all kinds of signals at every imaginable bit-rate has yet to be developed. Probably some compromises have to be made. Fully compensated spans could be realized, and if not, the performance monitoring of the channel is required to be done on a travelled path basis. This is possible by applying for example subcarrier tone modulation, which can be used for channel identification [3], dispersion monitoring [4] or PMD monitoring [5].

Returning to the matter of what capabilities an optical performance monitor technology should possess, a number of parameters can be assumed as basic requirements. They have been listed below:

- Individual channel power and composite channel power (total power of all WDM channels).
- Wavelength and wavelength drift.
- OSNR.
- Laser power and/or laser bias current.

Possible causes for bit errors can be amplifier degradations, which adds noise, a physical fibre cut, laser drifts and other equipment failures and degradations. These problems can be detected by monitoring a few and simple parameters such as the ones listed above. With the prospective introduction of optically switched networks, the number of significant optical signal parameters grows. Therefore, apart from these basic required parameters, additional optical signal parameters can be identified as possible candidates for monitoring:

- Dispersion
- PMD
- Channel crosstalk
- Spectral bandwidth
- Nonlinear scattering effects (SBS and SRS)
- Nonlinear effects (SPM, XPM and FWM)
- Q-factor
- BER

The last two, Q-factor and BER estimations are different from the rest as they evaluate the overall quality of the signal rather than a specific optical parameter. Ideally, monitoring the BER of a signal would be preferred as the number of bit-errors is the only true measure of the quality of the signal. However, the bits in a signal are random in nature and therefore it is practically impossible to monitor the exact BER.

As an alternative to making approximate BER evaluation, which can be rather complicated [6], a number of the above listed parameters can instead be monitored and used to evaluate the quality of the signal. This also brings along other advantages. Q-factor and BER evaluations do not provide sufficient information about the source of the signal degradation, whereas dispersion monitoring combined with OSNR monitoring can either confirm noise or dispersion changes as the source, or at least exclude those as possible reasons. The same holds for the BIP-8 bit-parity check done in SDH/SONET. An increase in bit-

errors does not explain the cause of the errors, so the OSNR and other physical parameters should be consulted.

It is difficult to state exactly which of the above listed items will be necessary to monitor and which will not. This will depend largely on the specific network and application in question. However, dispersion, Q-factor, and PMD qualify as very likely candidates considering the typical signal degradations found in high-speed all optical networks [7]. Monitoring various types of nonlinearities could also prove useful as new functionalities such as optical switching can alter the power levels in an optical fibre considerably [8] and thus excite various effects like SPM, XPM, FWM and SBS. Under normal circumstances though, these effects should be avoided by system design and power budget considerations. In those cases, monitoring of the nonlinear effects would not be strictly necessary if the power margins are large enough to assure no sudden variation or influence from these effects.

Dispersion and PMD variations are effects that can be difficult to avoid, especially as the O-E-O regeneration distances and the bit-rates increases. Combining dispersion monitoring and PMD monitoring with OSNR and Q-factor/BER evaluation could prove a likely candidate for optical performance monitoring in the physical layer, in the future all-optical networks. However, it depends on the specific network in question and other variations will unquestionably be possible.

4. Optical Signal Parameter Monitoring

This section will describe a method for optical signal parameter monitoring, in particular, chromatic dispersion monitoring. Dispersion is considered one of the parameters that is necessary to both monitor and compensate on-the-fly as both temperature changes, optical switching and dispersion slopes in a fibre can cause the dispersion of an optical signal to change.

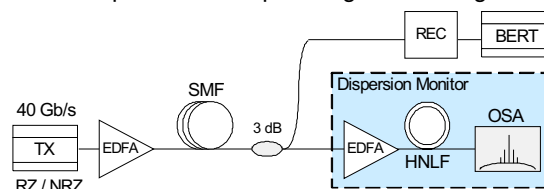


Figure 2 : Setup used to perform dispersion monitoring on 40 Gb/s RZ or NRZ signals.

The method described here is based on a spectral broadening in a highly non-linear fibre (HNLF) and has the advantage that it works for both RZ and NRZ.

Figure 2 illustrates the principle of the dispersion monitor. A 40 Gb/s signal is transmitted through SMF fibre to accumulate dispersion. A part of the signal is tapped off and amplified to 21 dBm in an EDFA. The amplified signal is sent to the HNLF, which is followed by a spectrum analyzer or optical filter in combination with a power meter. It is a well known fact that high pulse peak power excites nonlinearities in the HNLF and furthermore that nonlinearities cause the spectrum to broaden as seen in Figure 3a [9]. This is exploited such that the change of pulse shape caused by dispersion will dictate the broadening of the spectrum, and by filtering the signal, a dispersion monitoring signal can be realized [10].

Figure 3b shows the result in the case of dispersion monitoring of a 40 Gb/s NRZ signal. It shows both how the filtered power from the broadened spectrum follows the dispersion, but also how this correlates with the power

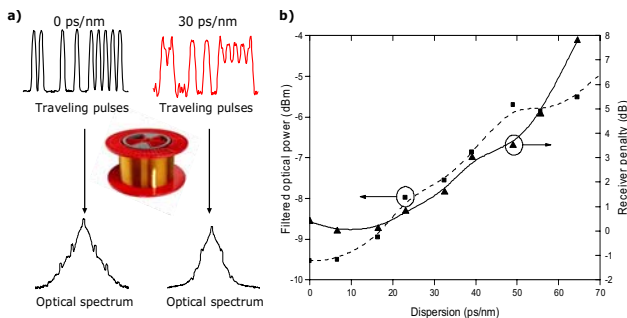


Figure 3: a) 40 Gb/s RZ spectrum under the influence of dispersion. The spectrum broadening clearly decreases when the pulse shape and peak power decreases. b) Experimental result that shows dispersion monitoring of a 40 Gb/s NRZ signal.

penalty in the receiver. As concluded above, OSNR monitoring is another optical signal parameter that is considered very important in optical performance monitoring. Figure 4 illustrates a method for OSNR monitoring using polarization interleaving between adjacent channels [11]. Polarization interleaving of adjacent channels is already implemented in dense WDM systems to reduce XPM and FWM [12]. Dense WDM systems also presents a problem in terms of OSNR monitoring as the channels are so closely spaced that channel sidebands overlap. This means that the traditional way of measuring OSNR, i.e. to extrapolate the out-of-band to the in-band noise level is no longer valid. By polarization interleaving adjacent channels they can be separated using a polarization beam splitter as illustrated in Figure 4 and the noise level between the channels is revealed allowing for an accurate OSNR evaluation.

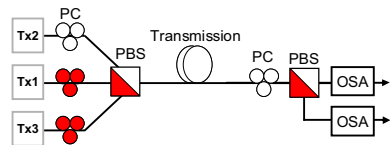


Figure 4: Polarization interleaving and splitting of adjacent channels to realize an OSNR monitor.

This was done in a three channel 10 Gb/s NRZ system using a 50 GHz channel spacing. Figure 5 shows the experimental results for the improved OSNR measurements. The straight line corresponds to the true OSNR and it is clearly seen how the polarization filtered OSNR is more accurate than the traditional method.

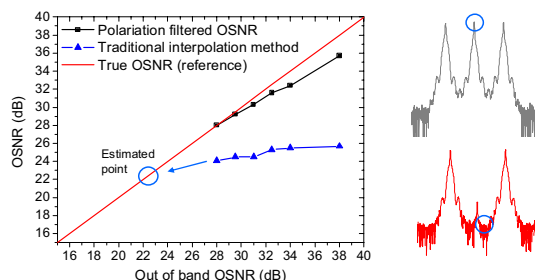


Figure 5: Principle illustration of the all-optical bit-parity calculation using a MZI interferometer with feedback. Notice the spectra's on the right - the bottom one reveals the noise.

5. Optical Signal Quality Monitoring

Parity checking is widely used today in the electrical domain, and as an example of a optical signal quality monitoring technology, a method for all-optical but parity calculations will be described here.

In general, bit parity checking it is not a complete error check as two errors within the same data block can pass undetected. However, the method provides a simple mean of error indication that is sufficient in many cases. This section describes a simple method of all-optical bit parity calculation using a Mach Zehnder interferometer (MZI) with integrated SOA's [13]. The method is a possible candidate for bit parity cheking in al-optical packet switched networks.

In the experiments, the optical XOR gate is accomplished using a MZI with integrated SOA's as illustrated in Figure 5. This type of MZI has previously been used successfully to realize logic functions such as OR and XOR [14], [15]. A 10 Gb/s RZ bit-word is input in the upper arm no. 1 and a 10 Gb/s clock is injected counter-propagating into the MZI in arm no. 4. If a feedback loop is set up, the resulting signal is fed back into the MZI and the bit-parity calculation operation has been achieved. The result, after a number of iterations, can be coupled out of the feed-back loop. Notice though, that in order to perform a sequential real-time parity calculation utilizing every bit in the bit-stream, the time-of-flight in this feed-back loop should match the bit time-slot exactly. Although not impossible, this requires exact integration of the entire MZI plus feed-back circuit, which was not an option in our experiments. Instead the focus was here to perform real-time parity calculations on selected bit's and thus simulating parity checking of an optical packet header.

This all-optical bit-parity calculation differs from other methods in running real-time. This means that the parity bit is calculated on-the-fly and can be inserted into a packet header without the need of any optical buffers.

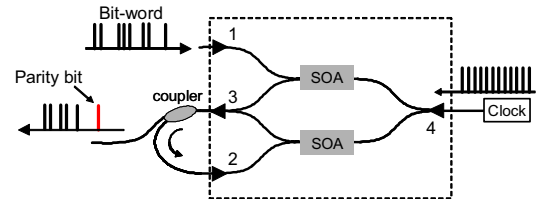


Figure 4: Principle illustration of the all-optical bit-parity calculation using a MZI interferometer with feedback.

6. Conclusion

This paper concludes that current optical performance monitoring technologies are not sufficient for the next generation all-optically switched networks. Several signal impairment effects will be enhanced with the increased optical transmitted distances and as a consequence, the legacy performance monitoring should be supported by optical performance monitoring in the physical layer. Experimental demonstrations of dispersion monitoring, OSNR monitoring as well as all-optical bit parity calculations were also shown.

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